Master en Ciencia y Tecnología de la Sostenibilidad

Trabajo Final de Master

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Barcelona - Junio 2017

# Assessment of the Potential of Energy From Agriculture Residues in Morocco

UPC

## ACKNOWLEDGMENTS

First and foremost I would like to thank my parents for their unconditional support patience, this work nor any would have been possible without your help.

A special thanks to my Director Enrique Velo for his help, valuable advice and guidance.

Another thanks must be given to Dr Abdelali Dakkina, Director of Strategy & Development at the National Agency for Energy Efficiency Morocco (AMEE), for his discussions, advice and providing me with data.

Thanks to all of the professors at the UPC, for all the knowledge transmitted, but most of all the passion and interest ignited in me, for such an important topic as Sustainability.

# ABSTRACT

In recent years, much attention has been focused on the use of renewable energies and its key role in combating global climate change. Countries are therefore looking for alternative sources to minimize greenhouse gas emissions while being able to respond to the growing needs of energy consumption.

The global volume of biomass generated annually from agriculture, equal to 140 billion metric tons, which is equivalent to approximately 50 billion tons of oil, could be transformed to a clean renewable energy and/or raw materials. These raw materials, made of biomass wastes, have attractive potentials and the shift to their use could considerably reduce the emissions of GHG but also provide renewable energy to some 1.6 billion people in developing countries, which still lack access to electricity.

**Morocco** is no exception according to biomass use opportunities. The country has, over the last decade, known a growth dynamic that is gradually changing its socio-economic profile.

In order not to hinder the growth dynamic that is taking place by securing adequate supplies of energy, but without jeopardizing sustained imbalance in external accounts, Morocco decided to act on its energy supply sources. In this respect, the promotion and development of renewable energies was identified as a priority under the new national energy strategy.

This strategy holds among its priorities the reduction of the country's dependence on fossil fuels, established today to almost 97%, a mastery of the demand (through improving energy efficiency), and the increase of the renewable energies share in the total energy mix, for a better contribution of the sector to the country's sustainable development efforts.

Morocco is characterized by the importance of its agricultural sector. Energy recovery of agricultural biomass is an opportunity to be seized to support Morocco's energy supply from renewable sources, and this work aims to estimate, as a first step of the assessment of the potential from biomass, to establish the global theoretical potential of energy from biomass in Morocco, and particularly agriculture residues.


*Keywords: Morocco, biomass, bioenergy, sustainability, renewable energies, theoretical potential.*

# RESUMEN


En los últimos años, mucha atención se ha centrado en el uso de las energías renovables y su papel clave en la lucha contra el cambio climático global. Por lo tanto, todos los países están buscando fuentes alternativas para minimizar las emisiones de gases de efecto invernadero y permitir responder a las necesidades crecientes de consumo de energía.

El volumen global de biomasa generado anualmente a partir de la agricultura, es igual a 140 mil miliones toneladas métricas, equivalente aproximadamente 50 mil miliones toneladas de petróleo, podría transformarse en una energía limpia renovable y/o en materias primas sostenibles. Estas materias primas, a base de residus de biomasa, tienen potenciales atractivos y el cambio a su uso podría reducir considerablemente las emisiones de GEI, pero también proporcionar energía renovable a unas 1.600.000.000 personas en los países en desarrollo, que todavía carecen de acceso a la electricidad.

Marruecos no es una excepción de acuerdo con las oportunidades de uso de biomasa. El país ha sabido, durante la última década, una dinámica de crecimiento que está cambiando gradualmente su perfil socio-económico.

Para no obstaculizar la dinámica de crecimiento que se está llevando a cabo, mediante la obtención de suministros adecuados de energía, pero sin poner en peligro el desequilibrio sostenido en las cuentas externas, Marruecos decidió actuar sobre las fuentes de su suministro energético. En este sentido, la promoción y desarrollo de energías renovables se identificó como una prioridad bajo la nueva estrategia energética nacional.

Esta estrategia tiene entre sus prioridades la reducción de la dependencia del país de los combustibles fósiles, establecida hoy a casi el 97%, un dominio de la demanda (a través de la eficiencia energética), y el aumento de la parte de energías renovables en el mix energético, para una mejor contribución del sector a los esfuerzos de desarrollo sostenible del país.

Marruecos se caracteriza por la importancia de su agricultura. La recuperación energética de la biomasa agrícola es una oportunidad que hay que aprovechar para apoyar el suministro energético de Marruecos a partir de fuentes renovables, y este trabajo pretende estimar, como primer paso, la evaluación del potencial de la biomasa, para establecer el potencial teórico global de la energía de la biomasa en Marruecos y, en particular, los residuos agrícolas.

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# INTRODUCTION

Worldwide demand for energy and resources will increase substantially, over the coming decades. The increase in the demand of energy will undoubtedly lead to more greenhouse gas emissions, while countries have agreed to reduce emissions in order to mitigate climate change.

In addition to that, energy security is fundamental issue nowadays, and renewable energies in general represent the main sustainable opportunity, along with a control of the consumption, to increase our independence from fossil fuels, such as oil and gas.

Biomass, such as organic waste, wood and agricultural crops, is often seen as one of the solutions. In addition og the energy potential, it could create a circular economy infrastructure in the field of the development of Biomass and closure of regional economic cycles, create new job opportunities and markets, but also improve the quality of life of rural populations.

# OBJECTIVES OF THE STUDY

*The main objectives are :*

- To identify the main biomass sources from the production of energy from agricultural residues
-To estimate the quantity of residues of these sources in order to translate the quantities of promising agricultural residues to actual potential of energy, and provide a starting point to further detailed assesments and pathways
- To conduct a literature review on biomass properties and processes for the production of energy, and the correlation between a biomass property and the suitable process
- To conduct a literature review on the drivers and barriers of the use of biomass, and the consideration of the sustainability criteria when assessing a bioenergy system
- To conduct a literature review on the calculation of residues from agricultural sources, and the biomass parameters and coefficients that allow the evaluation of the heating value of these residues
- To reach a set of conclusions and orientations on the biomass potential from agriculture in Morocco

# METHODOLOGY

A first part of this study is a synthesis of the research literature on biomass types, properties and transformation processes, highlighting the important concepts and characteristics that furtherly helped to understand and assess the suitable parameters to reach the objectives of the thesis.

The second part includes an introductory chapter on the general context of Morocco, which allowed us to know the prospective directions and pathways considered by the Moroccan government, and assessed by international entities (IEA and GIZ), gradually zooing in the biomass topic, which constitues the body of the study.

The first step is a quantitative research based on the comparison of statistical data (national level with Ministry of Agriculture data, and international, with FAO report), chosing the 2014/2015 period. The work focuses on the biomass ressources from agriculture, including crop residues and livestock waste, industrial residues and urban areas waste are therefore excluded.

The scope of the work, using a ressource focused approach, overlapped with the numerical data collected, allowed to establish a table of the principal national ressources exploitable for bioenergy uses.

Next, a realistic limitation of the relevant types/categories of biomass was done, using quantitative (i.e crop area, crop yielding and residue yielding per crop) and qualitative data (biomass quality and suitability, oriented by expert opinion). The criterias of selection will be further detailed in the respective chapter.

With regard to the relevant categories of biomass, harvesting as well as processing residues from chosen crops will be included, the olive and citrus processing residues are considered to be relevant in a mediterreanean country context, although being part of the agro alimentary industry.

This study, as a consequence of the theoritical nature of biomass potential, does not consider economical criterias. Direct costs, such as investment, labor or maintenance costs, nor indirect ones (compensations to farmers for lost nutrients for example) are not included in this thesis.

Detailed method relative to each part of the study will be discussed and illustrated in the practical case chapters.

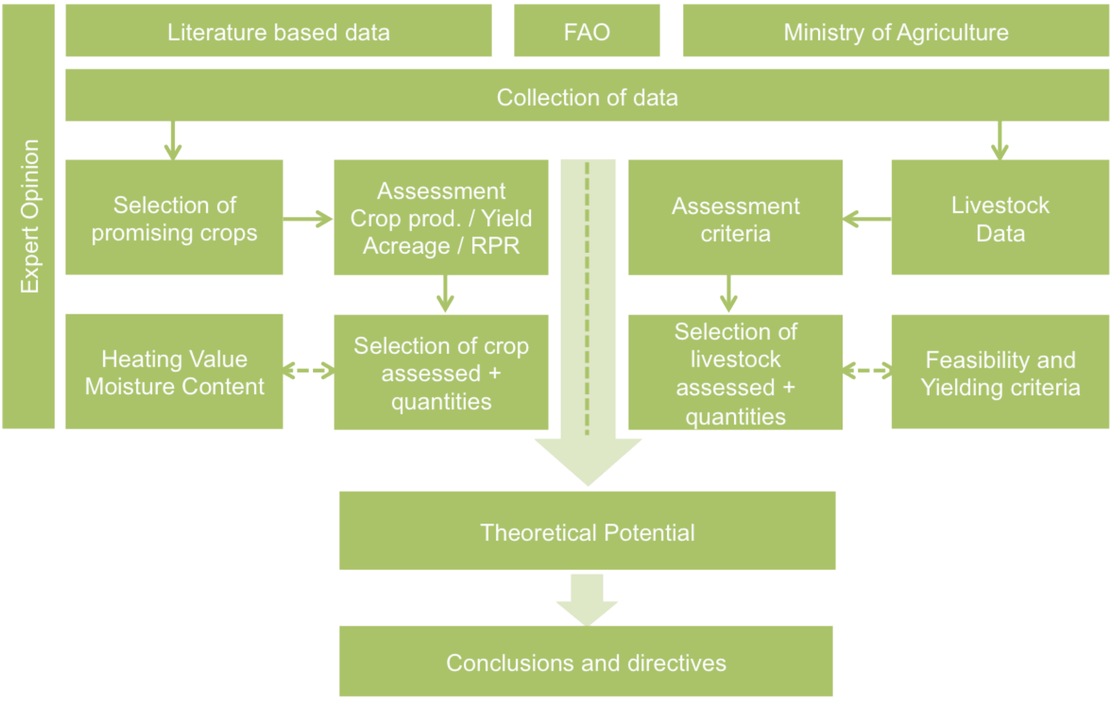


**Figure 1 Methology of the assessment**

# A) THEORY & CONCEPTS

Biomass is the term that defines the total mass of organic material in a biotope. It is produced in nature by the plant matter-living and dead residues, including all land- and water-based vegetation.

It can take the form of stalks, shells, algae, leaves, roots, or waste.

The energy stocked in the biomass is the result of the photosynthesis, as the chlorophyllous cells absorb the sunlight and convert the CO2 to an energy-rich carbon compound.

The different processes such as combustion or digestion allow to break the chemical bonds between adjacent atoms, releasing its embodied chemical energy.

The use of biomass as a source of energy production can provide a good alternative to the use of fossil energies, it is a renewable, steady and abundant supply, carbon neutral (as a primary source), mainly those biomass residues that are by-products of any agricultural activity.

| | North America | Latin America | Asia[b] | Africa | Europe | Middle East | Former Russia | World |
|---|---|---|---|---|---|---|---|---|
| Biomass potentials in EJ/a | | | | | | | | |
| Wood | 12.8 | 5.9 | 7.7 | 5.4 | 4.0 | 0.4 | 5.4 | 41.6 |
| Straw | 2.2 | 1.7 | 9.9 | 0.9 | 1.6 | 0.2 | 0.7 | 17.2 |
| Dung | 0.8 | 1.8 | 2.7 | 1.2 | 0.7 | 0.1 | 0.3 | 7.6 |
| (Biogas)[c] | (0.3) | (0.6) | (0.9) | (0.4) | (0.3) | (0.0) | (0.1) | (2.6) |
| Energy crops | 4.1 | 12.1 | 1.1 | 13.9 | 2.6 | 0.0 | 3.6 | 37.4 |
| Sum | 19.9 | 21.5 | 21.4 | 21.4 | 8.9 | 0.7 | 10.0 | 103.8 |
| Use in EJ/a | 3.1 | 2.6 | 23.2 | 8.3 | 2.0 | 0.0 | 0.5 | 39.7 |
| FPEC and HE[a] in EJ/a | 104.3 | 15.1 | 96.8 | 11.0 | 74.8 | 15.4 | 37.5 | 354.9 |
| Shares in % | | | | | | | | |
| Use/potential | 16 | 12 | 108 | 39 | 22 | 7 | 5 | 38 |
| Use/PFEC and HE[a] | 3 | 17 | 24 | 76 | 3 | <1 | 1 | 11 |
| Potential/PFEC and HE[a] | 19 | 143 | 22 | 195 | 12 | 5 | 27 | 29 |

[a] Primary fossil energy consumption (PFEC, including nuclear power) and hydroelectricity (HE).
[b] In Asia, current use exceeds available potential (i.e., biomass is used nonsustainably).
[c] Potential of biogas production from the available animal dung.

**Table 1 Biomass potentials and current use in different regions.**

# 1. Biomass types

There are numerous forms of classification for the different types of biomass, such as the one by final use (electrical/heat, transport fuel, or chemical feedstock), or provenance. In that case, it is often categorized as biomass derived from agriculture, forestry, industry, or urban areas[1].

Another form of classification would be the possibility of direct (combustion of the primary source) or indirect use (conversion to a solid or liquid fuel).

McKendry[2] uses a simple method to define four main types of biomass, this methodology being also partly used by D.L.Klass in his publication[3]:

## 1.1. Manures

Manure is the so-called agricultural waste derived from animal exploitation, such as farming and poultry. It is estimated that the world livestock and poultry would have represented 1.7 billion tons as a total dry weight[4].

Manure is often useful as a nutrient because it enhances soil properties, but it can also be used for energy production, provided that it is recycled and disposed of to avoid pollution.

Energy from farm manure can be directly generated by the combustion of its solids, or by anaerobic digestion, as the methane produced, when burnt, has less impact as a greenhouse gas than carbon dioxide (methane is 22 times stronger). Manure, being an intrinsically high-moisture material, is more suited to “wet” processing techniques[5], that we will detail further.

## 1.2. Herbaceous plants/grasses

Herbaceous plants refer to the biomass of grassy nature, it is mainly provided by agriculture, and can be subdivided into those with high- and low- moisture content, they are high in cellulose and moisture and were traditionally used for the biochemical conversion into liquids, such as ethanol.

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1 Kaltschmitt, M., and Hartmann, H., eds. Energy from Biomass. 2001

2 Mckendry. Energy production from biomass (Part 1): Overview of biomass. 2002
3 D.L.Klass. Biomass for Renewable Energy, Fuels, and Chemicals. 1998
4 Dr. John Sheffield. Farm Animal Manure is an Important Sustainable Renewable Energy Resource
5 Mckendry. Energy production from biomass (Part 1): Overview of biomass. 2002

They are characterized by the short rotation of the production cycle.

Grasses have different growing conditions, depending on the moisture content, nutrient balance, soil types.., which determines the suitability for an effective production rate in specific geographic location, but it always recommended to use the local widely spread plants as a safe source for energy production.

The fermentation of cellulose into glucose and its transformation to alcohol is easier to achieve on high-cellulosic biomass such as cereals or sugar cane and sugary/starchy feedstocks in general than woody species.

This type of biomass is more difficult to burn (compared to that of woody source), because of the higher amount of trace elements like chlorine and the lower ash content.

### 1.3. Woody plants

Wood has been the first and one of the most widely used source of energy by humankind, before being gradually replaced by fossil fuels. Still, according to the International Energy Agency, about 2.5 billion people in developing countries depend today on this source of energy just for cooking requirements.

Wood can be grown directly for energy production, and the wood products or residues all along the overall supply chain could be exploited as well. The paper production produces thinning woods as a by-product that can be used to close the life cycle of the product, with the necessity to treat it first in the case that it was contaminated with heavy metals[6] (coloring for example).

Woody plants are characterized by their relative slow growth, compared to herbaceous plants. It is composed by tightly bound fibers , high in lignin (which binds together the cellulosic fibers) unlike herbaceous ones, that contains lower proportion of lignin, having therefore more loosely tighten fibers, these differences in composition being an indication on what conversion process is more suitable.

It is important to emphasize the necessity to sustain a healthy production cycle when it comes to wood, with predetermined period for harvesting (typically during winter to early spring every third

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6 Kaltschmitt, M., and Hartmann, H., eds. Energy from Biomass. 2001

year), or removing roots from the soil after the biological lifetime of the tree to make land available for next crops.

The Geographical Information System (GIS) constitutes an important tool in forest management to provide crucial information about resources and can make planning and management of resources easier, for example, when recording and updating resource inventories, harvest estimation, planning, ecosystem management, landscape... are needed[7].

### 1.4. Aquatic plants

Aquatic plants such as seaweed, micro algae or aquatic plants have an important potential as a source of biomass energy. There are many advantages to use aquatic plants; their rapid growth (microalgae are the fastest growing photosynthesizing organisms), and high content in oils (the yield per acre of oil from algae is over 200 times the yield from the best-performing plant oils, according to Sheehan et al.,1998).

Another important advantage is that aquatic plants can be produced on non agricultural areas, and the fact that it doesn't generate a conflict on water consumption.

Usually, aquatic plants are mostly used as a source for biofuel, due to their high content in oil.

## 2. Biomass properties

### 2.1. Moisture content

Two types of moisture content are decisive in the study of the properties of a biomass source:

Intrinsic moisture: which is the moisture of the biomass source without the influence of any prevailing weather effect at the time of harvesting. This characteristic is only of interest under laboratory conditions. Thus not usable in our study.

Extrinsic moisture: the one of concern because the prevailing conditions of the weather are taken into account. The extrinsic moisture value is directly related to the appropriate conversion process utilized.

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7 Upadhyay M..2009

According to McKendry[8], a low moisture feedstock (typically <50%) is more suitable for a thermal conversion (case of woody plants), while bio-conversion processes such as fermentation, requires a high moisture feedstock (sugarcane for example or other high moisture herbaceous plants).

### 2.2. Calorific value

This property illustrates the heat value, or energy content released when the feedstock is burnt in the air. It can be expressed in two values, the higher heating value (HHV), representing the maximum amount of energy exploitable from a given biomass source, including the latent heat contained in water vapor, or the lower heating value (LHV), which is, in practical terms, the appropriate value for the actual amount of energy recovered, varying from one conversion technology to another.

The moisture content should be stated along with the calorific value of biomass materials, as it reduces the total available energy.

### 2.3. Proportion of fixed carbon and volatiles

The volatile content or matter (VM) refers to the portion of gas from the biomass that is released when heated (to 950° for 7min).

During the heating process, biomass decomposes into a volatile part and a solid char. The solid mass obtained, excluding the ash and moisture content, is called the fixed carbon content (FC).

### 2.4. Ash/residue context

The chemical breakdown of any biomass (bio-chemical or thermo-chemical) produces a solid residue, which, in the case of a combustion in the air, is called "ash", and constitutes the non-combustible inorganic residue that remains after burning the biomass.

In the case of a bio-chemical transformation, the solid residue percentage is greater than the ash content in a thermo conversion process.

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8McKendry. Energy production from biomass (part 1): overview of biomass.2001

The byproduced ash has different alternatives to be reused depending of its content, as a fertilizer for example in the case of ash rich in Mg and Ca, and very low in heavy metal content.

### 2.5. Alkali metal content

The plants naturally require metals to grow, Potassium being the dominant alkali metal in most biomasses. The alkali metal content is important to highlight in any thermo chemical conversion process, in the case of sodium(Na), calcium(Ca), potassium(K) or magnesium(Mg) for example, the reaction with the silica present in the ash produces a sticky liquid phase that could lead to blockages of the airways of the boiler plant and cause corrosion.

This content could be reduced by a water leaching treatment as these metals are highly water-soluble, thus removing up to 70% of the alkali metals.

### 2.6. Cellulose/lignin ratio

Biomass contains generally 35% to 50% of cellulose. The cellulose/lignin content is important to highlight when a biochemical conversation is involved. The biodegradability of cellulose is much higher than that of lignin, hence the importance of the proportions to consider for biochemical conversion processes.

For the production of ethanol, plants with a higher cellulose/hemi-cellulose content are needed to provide a high yield. To illustrate the effect of cellulose content on yield, up to 280l/t of ethanol can be produced from switchgrass, compared with 205l/t from wood, an effect largely due to the increased proportion of lignin in wood[9].

### 2.7. Bulk density

The importance of this property is related to transport and storage disposals.

Bulk density impacts on fuel storage requirements, sizing of the materials handling system and it gives us indications on the behavior of the material during thermo-chemical processing.

9 McKendry, 2001. Energy production from biomass (part 1): overview of biomass

| Biomass | Moisture Content | Bulk Density, $\rho_b$ (kg/m$^3$) | | | |
|---|---|---|---|---|---|
| | | a | b | $R^2$ | RMSE[a] |
| Wheat straw | 8 | 113.79 | 0.39 | 0.98 | 5.08 |
| | 20 | 98.80 | 0.32 | 0.97 | 3.08 |
| | 40 | 161.64 | 0.43 | 0.99 | 6.63 |
| | 60 | 290.71 | 0.51 | 0.99 | 14.51 |
| Switchgrass | 8 | 502.10 | 0.57 | 0.98 | 11.04 |
| | 20 | 378.10 | 0.49 | 0.96 | 10.58 |
| | 40 | 479.77 | 0.52 | 0.94 | 16.50 |
| | 60 | 938.03 | 0.61 | 0.93 | 26.18 |

[a] The root mean square error.

**Table 2 Relationship between biomass particle size and bulk density (P. S. Lam et al.,2008)**

## 3. Transformation processes

The conversion of the biomass to an energy source or a bioenergy can be achieved through different processes according to numerous factors of choice such as : the type of biomass and some properties that we already mentioned, quantity available, economic conditions, but also the final use or the desired form of energy.

The three main categories of energy conversion technologies are thermo-chemical, bio-chemical, and mechanical(using esterification to produce biofuel).

The figure below shows the different routes for a conversion from biomass to energy and fuels.

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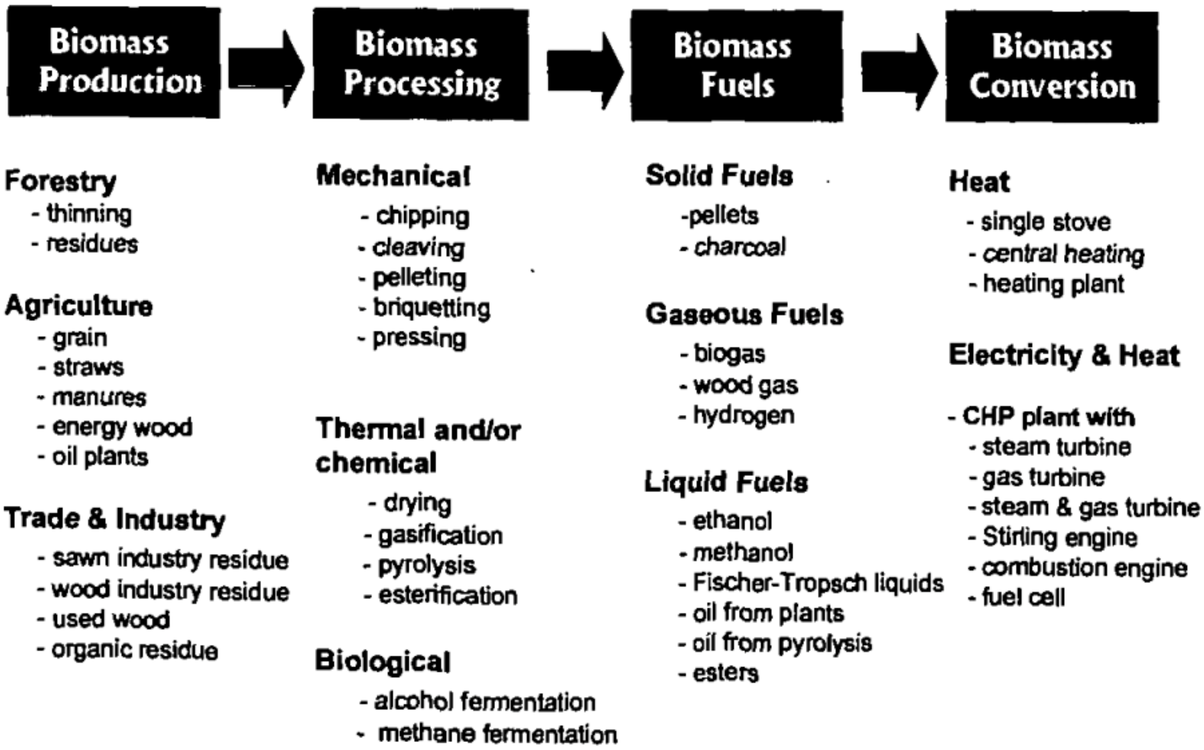


**Figure 2 From biomass to energy and fuels (Chum & Overend 2001)**

### 3.1. Thermo-chemical conversion

This conversion takes place at high temperatures, each of its different processes require different concentrations of oxygen and produce a different product for a specific use.

Thermo-chemical conversion processes include:

#### *3.1.1. Combustion*

Combustion is the most used process to convert biomass in energy globally. According to McKendry[10], it is possible to burn any type of biomass but in practice combustion is feasible and worthy only for biomass with a moisture content < 50%, unless the biomass input is pre-dried.

10 Peter McKendry, Energy production from biomass (part 2): conversion technologies. 2001

The principle of combustion is a complete oxidation of the carbon in biomass to carbon dioxide, hydrogen to water, sulfur to sulfur dioxide, and nitrogen to nitrogen oxides. The scale of a combustion plant can vary from very small scale to large scale plants in the range of 100-3000 MW.

Co-combustion of biomass in coal-fired powered plants is a productive option because of their high conversion efficiency.

### *3.1.2. Gasification*

In this process, the partial oxidation of biomass at high temperatures (800-1000°C) converts it from a carbonaceous gas to a combustible gas mixture called product gas or syngas.

An important process to highlight would be the "biomass integrated gasification/combined cycle" (BIG/CC), where the integration of gasification and combustion/heat recovery ensures a high conversion efficiency (40-50% based on the lower heating value of the input gas) for a plant of 30-60 MW efficiency.

The different steps of gasification include the initial pyrolysis, where the biomass is heated at high temperatures in the absence of oxygen. The volatile vapors, that constitutes around 70-80% on a dry basis[11] (mainly hydrogen, carbon monoxide, methane, hydrocarbon gases, tar and water vapor) are separated from the char at this stage. During the next steps, gasification breaks down the pyrolysis products, thus degrading the tars to smaller molecules and converting the char into gas, mostly carbon monoxide, dioxide and hydrogen, depending of the gasifier technology, with the water-gas shift reaction changing the concentrations of the different gases and steam within the gasifier.

The gas produced can be burnt directly, but can also be used as fuel in internal combustion engines or turbines, or as a feedstock in the production or chemicals, like methanol for example that has a future as a fuel for transportation.

In general, biomass combustion aims to generate heat, whereas the purpose of gasification is the production of valuable gases that could be burnt directly or stored for other applications. Actually,

11 E4tech. Review of technology for the gasification of biomass and wastes. June 2009

gasification is considered to be more environmental friendly because its emits lower toxic gases into the atmosphere. The following table[12] summarizes the comparison between the two processes:

| Features | Gasification | Combustion |
|---|---|---|
| Purpose | Creation of valuable, environmental friendly, usable products from waste or lower value material | Generation of heat or destruction of waste |
| Process Type | Thermal and chemical conversion using no or limited oxygen | Complete combustion using excess oxygen (air) |
| Raw Gas Composition (before gas cleanup) | $H_2$, CO, $H_2S$, $NH_3$, and particulates | $CO_2$, $H_2O$, $SO_2$, $NO_x$, and particulates |
| Gas cleanup | Syngas cleanup at atmosphereic to high pressures depending on the gasifier design | Flue gas cleanup at atmospheric pressure |
| | Treated syngas used for chemical, fuels, or power generation | Treated flue gas is discharged to atmosphere |
| | Recovers sulphur species in the fuel as sulphur or sulphuric acid | Any sulphur in the fuel is converted to $SO_2$ that must be removed using flue gas primarily consists of $CO_2$ and $H_2O$ |
| Solid byproducts/ products | Char or slag | Bottom and fly ashes |
| Ash/char or slag handling | Low temperature processes produce a char that can be sold as fuel | Bottom ash and fly ash are collected, treated, and disposed as hazardous waste in most cases or can be sold as a material for making concrete [71] |
| | High temperature processes produce a slag, a non-leachable, non-hazardous material suitable for use as construction materials | |
| | Fine particulates are recycled to gasifier. In some cases fine particulates may be processed to recover valuable metals | |
| Pressure | Atmospheric to high | Atmospheric |

**Table 3 Comparison between gasification and combustion routes (Rezaiyan and Cheremisinoff, 2005)**

### *3.1.3. Pyrolysis*

Pyrolysis is the process in which biomass is heated at high temperatures in the absence of air. The products are gases, liquids (in the form of pyrolysis oil), and char. The temperature in this process is usually between 400°C and 800°C, which is relatively low compared to gasification.

12 Rezaiyan J, Cheremisinoff NP. Gasification technologies – a primer for engineers and scientists. Boca Raton (FL): CRC Press Taylor & Francis Groups. 2005.

We can roughly divide pyrolysis to fast flash one and slow one, the former usually having the highest heating rate and the greatest pyrolysis oil yield, that can be used as a source of fuel in combustion boilers or refined into transportation fuels, while the latter mainly produces char or charcoal.

Fast pyrolysis, consisting of a rapid intense heating (more than 1000°C/sec) produces 60-75% wt of liquid bio-oil, 10-25% wt of solids (char) and 10-20% wt of noncondensable gases[13]. These remaining noncondensable gases can be reused as a source of energy for the pyrolysis reactor.

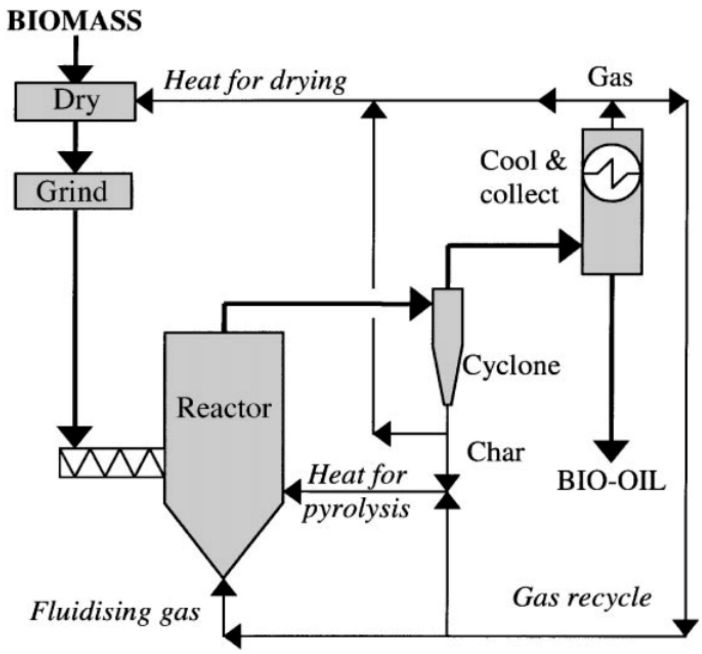


**Figure 3 Conceptual Fluidized bed fast pyrolysis process**

Bubbling fluid bed pyrolysers (BFB), or more commonly called fluidized beds, are the most used configurations due to the easy operation, good temperature control and very efficient heat transfer to biomass particles due to high solid density. A typical bubbling fluid bed configuration is demonstrated in Figure 5, including the preliminary steps of drying and grinding of the input to minimize the water content in the product pyrolysis oil and ensure a rapid reaction.

13Dinesh Mohan, Charles U. Pittman et al,. Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. 2005

A number of barriers remain for the advance of fast pyrolysis technologies, including the liquid product quality upgrade or the adaptation of the technology to the uses and applications for the pyrolysis to be more cost competitive.

### *3.1.4.Liquefaction*

Liquefaction is the thermo-chemical conversion of biomass into a stable liquid using low temperatures and high hydrogen pressures. Direct liquefaction is similar to pyrolysis in terms of the product targeted, which is the liquid part, they differ however in terms of the process, as liquefaction does not require a preliminary drying of the input, but catalysts are crucial. Liquefaction requires a low reaction temperature but higher than pyrolysis.

In general, the conversion of biomass into liquid hydrocarbons starts with the pre-treatment of the feedstock, the slurrying  the feedstock within a liquid carrier (at this stage catalysts can be added), the slurry is then heated to reach reaction conditions, the reducing gas are added to trigger the main reaction, causing the product (solid-liquid) separation and the recovery of solvent.

A generalized conceptual flow sheet for liquefaction from McKendry is shown in Fig. 6.

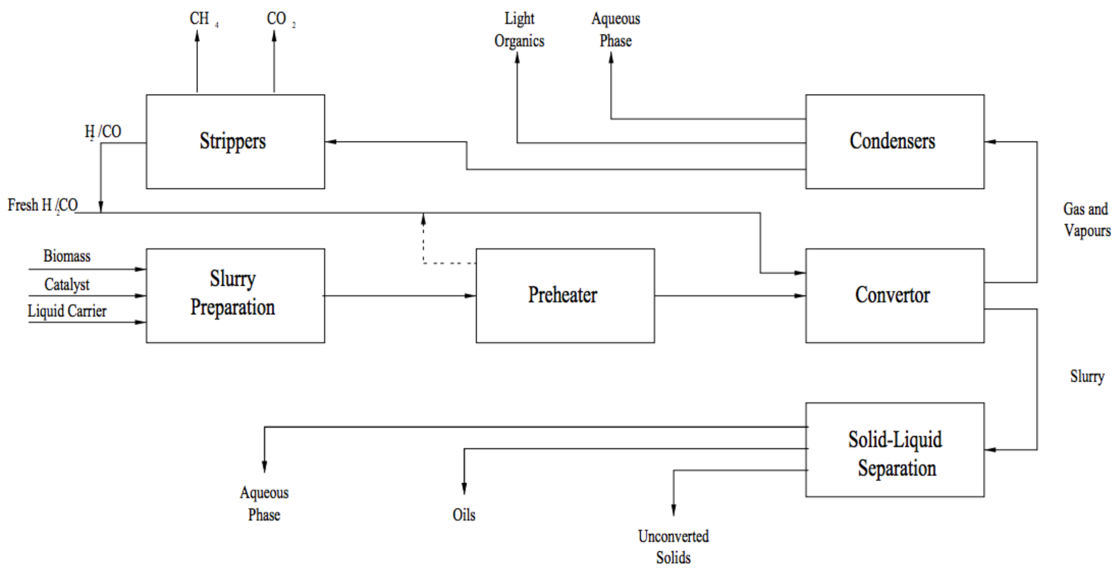


**Figure 4 Flow sheet for liquefaction.**[14]

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14Peter McKendry, Energy production from biomass (part 2): conversion technologies. 2001

The two typical groups of catalysts usually employed in biomass liquefaction are alkalis and acids, the catalysts being a critical factor in biomass liquefaction as it can reduce the required reaction temperature, enhance reaction kinetics, and improve the yield of desired products[15].

The type of biomass input widely used in liquefaction is the lignocellulosic biomass for the production of bio-oil, because they are rich in hydroxyl groups.

The liquefaction process holds an important potential, in particular for the production of specific fuels or combustion purposes, research and development should therefore be encouraged in order to progress and solve some remaining technology problems.

The figure 7 summarizes the different thermo-chemical processes to produce energy from biomass, the different products depending on the process and the potential final use of the product.

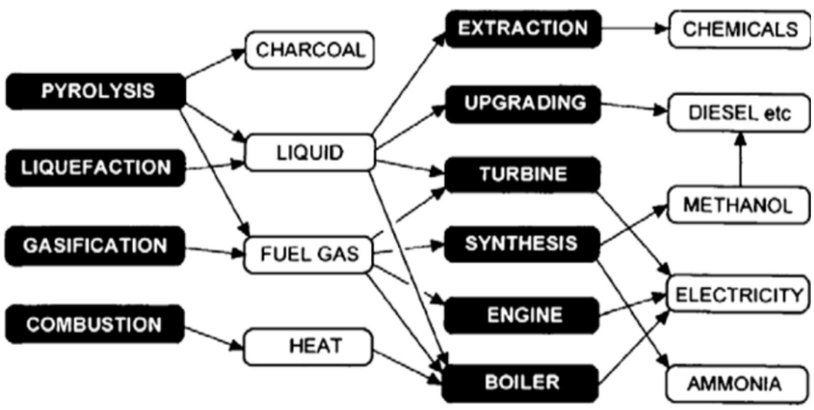


**Figure 5 Thermo-chemical processes for bioenergy production and the corresponding**

### 3.2. Bio-chemical conversion

In the case of high-moisture materials, manures for example, the thermo-chemical conversion processes mentioned previously would consume more energy than the actual energy produced. Thus, it results more economical and efficient to use one of the biochemical conversion processes that we develop bellow:

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15Maldas D, Shirai N. Liquefaction of biomass in the presence of phenol and H2O using alkalies and salts as the catalyst. Biomass Bioenergy. 1997

### *3.2.1.Anaerobic digestion*

Anaerobic digestion is the conversion of biomass material to biogas by a microbial consortium, a mixture of methane and carbon dioxide (with small quantities of other gases),applying the biological methanogenesis (production of methane). This process, mainly recommended for high moisture content organic materialis executed in an oxygen-free environment, and has the advantage of producing less biomass sludge in comparison to aerobic processes but also to remove pathogens more effectively. The biogas produced has an energy content of about 20-40% of the lower heating value of the feedstock[16], and usually ranges from 14 to 29 MJ/m3[17].

The biogas produced, which composition is typically from 50% to 70% of methane and 30% to 40% carbon dioxide with traces of hydrogen sulfide and water vapor, can be used directly to produce heat and power, but can also be upgraded to a higher quality (purification)by the removal of $CO_2$ in order to be used as transportation fuel for vehicles.

In a first step of the process, feedstock is collected and shredded, before being placed into a reactor containing the microorganisms required for the methane fermentation, directly or as a slurry. The tank reactor is continuously fed and stirred, with an usual hydraulic retention time of 15 to 20 days - up to 30,and a mesophilic temperature of about 35°C, important for the dynamic equilibrium of the three converting different kinds of bacteria. This bacteria can be classified to fermentative and acetogenic, that degrade the complex organic compounds of biomass into simpler molecules, followed by the methanogenic bacteria that convert the intermediate products to methane and carbon dioxide. The solids obtained can be recycled and used as a fertilizer or animal feed, but also transformed through thermochemical conversion. The following table shows the expected biogas yields for different substrates:

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16Peter McKendry, Energy production from biomass (part 2): conversion technologies. 2001

17Kaltschmitt M, Thran D, Smith KR, Renewable Energy from Biomass. 2003

| Material | Yield of biogas in m³/t organic dry matter | Material | Yield of biogas in m³/t organic dry matter |
|---|---|---|---|
| Liquid manure from beef | 250 | Paunch content | 420–520 |
| Liquid manure from pork | 480 | Rey straw | 300–350 |
| Droppings from chicken | 450 | Potato herbs | 560 |
| Sewage sludge | 400 | Sugar beet leaves | 550 |
| Organic waste from households | 170–220 | Food residues | 80–120 |
| Waste fat | 1040 | Waste water from brewing industries | 500 |
| Roadside green | 550 | Waste water from sugar industries | 650 |

**Table 4 Thermo-chemical processes for bioenergy production and the corresponding**

*3.2.2. Fermentation*

This process is already used on a large scale in order to produce ethanol from sugary and starchy crops, but also on lignocellulosic biomass, the process involving an acid or enzyme treatment (hydrolysis). During fermentation, yeast or bacteria produce alcohol (ethanol or butanol for example) as a final product by splitting organic matter.

The process starts by a simple pre-treatment of the biomass, that includes chopping or crushing and washing with hot water. The pre-treatment aims to remove the plant material and open the cell walls to make the starch (molecule too large to ferment directly) and other components accessible.

During hydrolysis process, starch and cellulose/hemicellulose are broken down to simple sugars of one or two molecules, and liquefied in the presence of acid and/or enzymes (α-amylase for example), and then saccharified by treating with another enzyme to smaller, fermentable sugars[18].

During fermentation, the microorganisms digest the sugars to convert them to energy and chemicals for their subsistence, giving by-products such as ethanol, hydrogen and carbon dioxide.

Specific concentrations of sugar, nutrients, temperature and pH should be maintained and adjusted for the process.

18 Wisbiorefine 2004.

This fermentation produces gases that can be captured for a commercial use, but mainly ethanol, that has various properties such as a high heat of vaporization, low flame temperature, a greater gas volume change[19].

Below is a simplified flow diagram of a biomass to ethanol conversion using hydrolysis and fermentation:

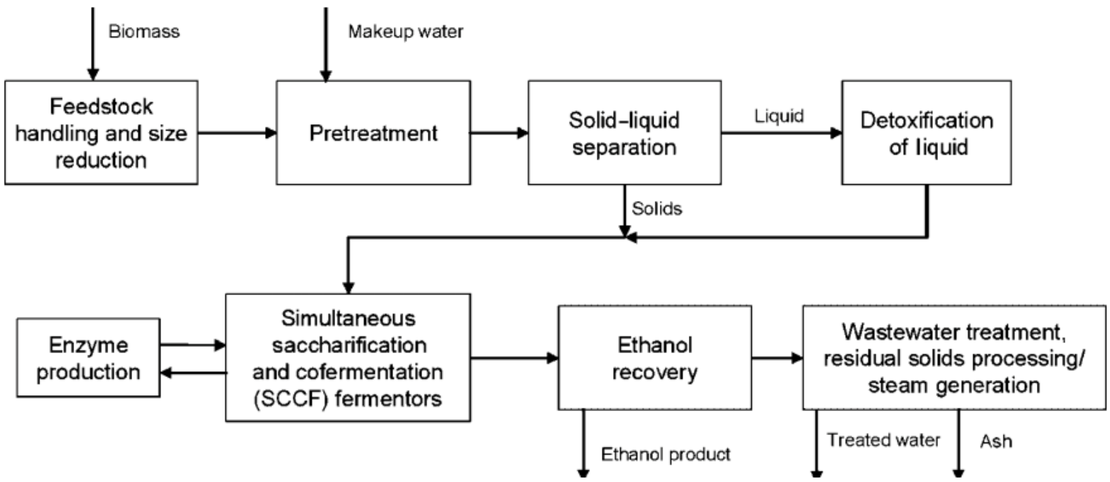


**Figure 6 Simplified flow diagram for a biomass-to-ethanol process utilizing enzymatic hydrolysis and simultaneous saccharification and cofermentation[20].**

## 4. Drivers and barriers to the use of biomass

Biomass has historically been benefiting millions of households in the form of cooking, heating and compost.

The first driver for the promotion of bioenergy could be the necessity and growing need to lower the amount of GHG, associated with the desire to find more sustainable ways to produce biomass. When produced with sustainable means, biomass emits the same amount of carbon during conversion as is taken up during the growth of the plant. In the process of renewing the used plant materials, the new plant absorbs an equal quantity of carbon, therefore developing neutrality in the carbon balance.

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19 Wyman CE, Biomass ethanol: technical progress, opportunities, and commercial challenges. Annu Rev Energy Environ. 1999

20Wyman CE, Biomass ethanol: technical progress, opportunities, and commercial challenges. Annu Rev Energy Environ. 1999

Most biomass sources being in rural areas, the promotion of bioenergy could have a positive impact on improving the standard of living of these areas and help create or maintain rural employment.

It is also an interesting opportunity to increase energy security and minimize overdependence on traditional electricity, especially in off-grid communities. With such improvements, land abandonment would be avoided, agricultural competitiveness improved and diversified income streams would be provided to farmers, thus creating a large positive effect on local populations.

The production of biomass could, on a wider scale, if the appropriate crops are selected, help restore degraded lands and increase biodiversity. It is a largely available source in most countries on a renewable basis, naturally or through the recycling of by-products of human activities.

All these drivers, combined with the great technological improvements that have been made, concerning the conversion processes but also the crop production, allowing to produce biomass at a lower cost and with a higher conversion efficiency than previously, allowed biomass to get more interest.

However, several barriers remain to the sustainable development of this energy source, and some critical key factors should be taken into consideration, such as the amount of land and water resources needed to support biomass production.

In fact, the long-term potential of bioenergy relies primarily on the land availability, and an increase of biomass feedstock production can have both positive and negative impact (soil quality and biodiversity), leading to restrictive and incentive regulations. Therefore, it is required for the policy makers to ensure a sustainable demand and production of bioenergy through a regulation of the chain and the land/water use.

Another possible barrier could be the bulky and sparse nature of biomass sources, making it expensive and difficult to transport, export and trade regionally and internationally. It is a local activity (generally within 100km) and it is location dependent. This characteristic makes it sensible to a well planned technical infrastructure and logistics, and depend of a good supply and transformation chain.

The technical skills, i.e data comparing energy technologies for its equivalent services, or norms and standards in terms of energy performance manufacture, installation and maintenance are limited, and lack of data is due to the fact that a large fraction of the energy economy operates outside the formal economy, or, it is distributed among different organizations that do not cooperate.

This panorama leads to a general lack of awareness of the modern options for biomass energy, the costs and benefits of the range of technologies available nowadays, intensified by the limited in-country capacity for data collection and analysis.

On an institutional level, biomass related services are dealt with by various agencies and ministries on different levels, making a fluid coordination harder to achieve. The different decision-makers, usually responsible of controlling the budget, have little interaction and communication with operational level agents, and on a larger scale, there is a lack of integrated policy and regulatory framework to encourage the use of bioenergy.

A correct coordination would provide a holistic view of risks and benefits and therefore allow a correct linkage between biomass energy use and income generation activities, therefore helping overcome the financial barrier of the high-capital cost of bioenergy technologies investments, which usually represents the principal obstacle for choosing biomass.

## 5. Sustainability criteria

Parallel to the growing interest in energy from biomass, concerns related to food security, GHG, or other challenges mentioned in the previous chapter brought the debate towards the need for sustainability criteria.

Various organizations started therefore developing a biomass certification system, combined with principles and criteria to reach a sustainable bioenergy lifecycle at all stakeholder levels.

The EU Commission presented a report in 2010 establishing a list of voluntarily sustainability requirements for all bioenergy carriers to adopt by the EU Member States in order to receive government support or count towards national renewable energy targets.

The criteria include topics such as GHG savings (50% in comparison with fossil fuels in 2017) but also land use considerations, given that bioenergy crops cannot be grown in areas converted from land with previous high carbon stock (wetland or forest), or other measures to preserve published a first report in 2011 including 24 sustainability indicators established in the three characteristic sub-groups of sustainability: - Environmental, co-led by Germany and UNEP;Social - led by FAO; and Economic and Energy Security – co-led by IEA and UN Foundation. These 24 indicators are accompanied by methodology sheets, including support information and a methodological approach[21].

Furthermore, a relevant study was achieved by Buchholz, Luzadis and Volk[22]with the objective of analyzing how key experts in bioenergy would perceive and classify the 35 criteria of sustainability found in assessment frameworks. They were asked to rate the criteria for attributes of relevance, practicality, reliability and importance, and the outcomes of the survey showed that the highest ratings were received by the criteria of energy balance, GHG, soil protection, and participation, with environmental criteria in general, rated as more important and relevant while economic criteria were perceived as more reliable and practical. The table below shows the average rating of criteria, ranked by importance rating:

| Criterion no. | Criterion name | Nature of criterion | Relevance rating | Practicality rating | Reliability rating | Importance rating |
|---|---|---|---|---|---|---|
| 34 | Greenhouse gas balance | Environmental | 2.84 | 2.33 | 2.17 | 3.55 |
| 21 | Energy balance | Environmental | 2.87 | 2.51 | 2.39 | 3.44 |
| 30 | Soil protection | Environmental | 2.85 | 2.23 | 2.07 | 3.27 |
| 4 | Participation | Social | 2.80 | 1.98 | 1.95 | 3.16 |
| 32 | Water management | Environmental | 2.74 | 2.12 | 2.00 | 3.14 |
| 22 | Natural resource efficiency | Environmental | 2.78 | 2.02 | 1.86 | 3.11 |
| 17 | Microeconomic sustainability | Economic | 2.74 | 2.46 | 2.30 | 3.10 |
| 1 | Compliance with laws | Social | 2.46 | 2.13 | 1.95 | 3.09 |
| 24 | Ecosystems protection | Environmental | 2.87 | 1.98 | 1.95 | 3.07 |
| 13 | Monitoring of criteria performance | Social | 2.73 | 2.12 | 2.02 | 3.02 |
| 2 | Food security | Social | 2.53 | 1.91 | 1.79 | 2.95 |
| 33 | Waste management | Environmental | 2.70 | 2.39 | 2.23 | 2.93 |
| 20 | Adaptation capacity to environmental hazards and climate change | Environmental | 2.63 | 2.05 | 1.80 | 2.90 |
| 26 | Crop diversity | Environmental | 2.48 | 2.10 | 1.95 | 2.86 |
| 8 | Working conditions of workers | Social | 2.65 | 2.27 | 1.98 | 2.83 |
| 12 | Planning | Social | 2.47 | 2.22 | 2.03 | 2.79 |
| 19 | Economic stability | Economic | 2.51 | 1.98 | 1.79 | 2.79 |
| 23 | Species protection | Environmental | 2.51 | 1.74 | 1.68 | 2.76 |
| 29 | Use of chemicals, pest control, and fertilizer | Environmental | 2.53 | 2.23 | 2.07 | 2.72 |
| 35 | Potentially hazardous atmospheric emissions other than greenhouse gases | Environmental | 2.57 | 2.26 | 2.17 | 2.72 |
| 16 | Employment generation | Economic | 2.51 | 2.33 | 2.15 | 2.69 |
| 11 | Property rights and rights of use | Social | 2.55 | 2.00 | 1.76 | 2.68 |
| 31 | Land use change | Environmental | 2.40 | 1.79 | 1.64 | 2.68 |
| 28 | Use of genetically modified organisms | Environmental | 2.44 | 2.07 | 1.85 | 2.64 |
| 25 | Ecosystems connectivity | Environmental | 2.44 | 1.91 | 1.71 | 2.57 |
| 7 | Respect for human rights | Social | 2.28 | 1.55 | 1.50 | 2.48 |
| 18 | Macroeconomic sustainability | Economic | 2.30 | 1.83 | 1.89 | 2.39 |
| 5 | Cultural acceptability | Social | 2.23 | 1.58 | 1.45 | 2.37 |
| 9 | Respecting minorities | Social | 2.20 | 1.62 | 1.45 | 2.35 |
| 27 | Exotic species applications | Environmental | 2.18 | 1.88 | 1.69 | 2.33 |
| 6 | Social cohesion | Social | 2.16 | 1.62 | 1.46 | 2.26 |
| 3 | Land availability for other human activities than food production | Social | 2.18 | 1.70 | 1.63 | 2.25 |
| 10 | Standard of living | Social | 2.14 | 1.77 | 1.67 | 2.14 |
| 15 | Noise impacts | Social | 2.00 | 2.05 | 2.02 | 2.10 |
| 14 | Visual impacts | Social | 2.02 | 1.81 | 1.55 | 1.98 |
| Overall average rating | | | 2.49 | 2.01 | 1.87 | 2.75 |
| Consensus (std. deviation) | | | 0.25 | 0.26 | 0.25 | 0.38 |

**Table 5 Average rating of criteria for all attributes, ranked by importance rating.**

21The Global Bioenergy Partnership Sustainability Indicators for Bioenergy, 2011.

22Thomas Buchholz, Valerie A. Luzadis, et al. Sustainability criteria for bioenergy systems: results from an expert survey. 2009

This study additionally highlighted the agreements and disagreements on the importance of criteria among the experts, with a tendency for greater disagreement in the rating of the importance of social criteria compared to environmental ones, also ranked the lowest in reliability and practicality.

It is clear that continued dialogue is needed to achieve consensus about the importance of the criteria and move the discussion on sustainability of bioenergy systems forward. A single fixed set of criteria might not be advisable for bioenergy assessment, hence the suggestion of a more flexible framework for different spatial and temporal scale, and to apply to each project independently, with a common basis of agreed criteria (i.e the top third most important for the three legs of sustainability), for a more process oriented approach than a goal oriented one.

We should remember that the use of biomass does not automatically imply that its production, conversion and distribution are sustainable, and that sustainability as a social value is controversial by nature, some valuing the three aspects equally when assessing, while others supporting the view of a nested components sustainability. Sustainability criteria should therefore be developed through a transparent and fair process, taking into account local conditions and a multi-stakeholder approach, in order to provide insights on the required actions for the development of  sustainable bioenergy.

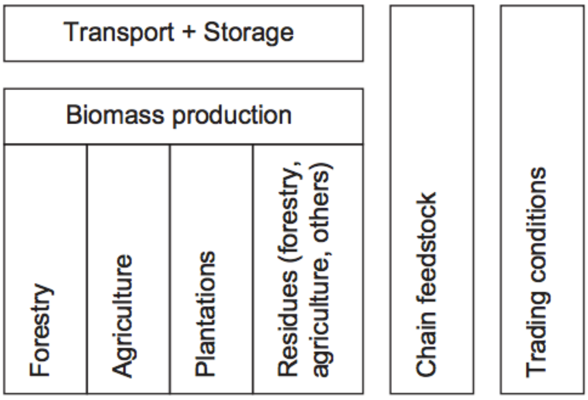


**Figure 7 Existing areas demanding criteria and indicator development for sustainable biomass trade[23].**

23Van Dama, J et al., Overview of recent developments in sustainable biomass certification. 2008

## Conclusion

The first part of the study was a review of the existing literature of biomass properties, biotransformation processes, and the considerations related to its use, economically, socially and on a policy/institutional level.

It helped us understand the extent of the properties and characteristics inherent to biomass sources, and how they influence the choice of the transformation process and its efficiency.

In addition to that, the analysis of the drivers and barriers allowed to apprehend the numerous advantages and drivers related to bioenergy and the positive impact resulting from its use, but also the eventual barriers to be faced when making this choice.

Finally, the sustainable criteria opened us to the wide complexity and transversality of the sustainable use of biomass and the many dimensions it encompasses, as well as the controversial establishing of a valid criteria and either it should be set or left to determine independently for each project specifications. It is an interesting topic that requires a deepr analysis in a further study.

# B) STUDY CASE

## 1. Background

In an increasingly unstable international economic environment, Morocco, as an emerging economy, remains resilient and experiences a steady growth of 2 to 5 percent for the last 10 years, with a registered growth of 4,5 in 2015 (World Bank Data). Its low volatility and political stability allowed Morocco to position itself as an economic hub between the markets of EU and the African continent.

The Moroccan economy has a dual character, characterized by a fairly modern industrial and tertiary sector, with an important share in the traditional agricultural sector, which makes it largely dependent on the climate. The industrial sector is highly concentrated in three manufacturing sectors, the chemical industry, the agri-food, and the textile and leather industries, its share in the total GDP being in 2012 of 15,9% compared to 14,2 in 2008[24]. The tertiary sector is growing significantly in the last decade, and we observe that the Moroccan economy is currently shifting toward a new growth model based on increasing the shares of higher value-added industries and services, the main weakness of the economy remaining the significant weight of the informal economy (which is detrimental to public finances),

As a result of the stable annual growth, Morocco has significantly improved its Human Development Index (HDI), that increased from 0.351 in 1980 to 0.617 in 2014[25].

Despite its recent progress, Morocco still faces considerable socio- economic challenges, like the strong national poverty index, and the high level of illiteracy, with the urban areas anticipated to be affected by a high growth rates and rural migration flows.

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24Mansour and Castel, 2014

25United Nations Development Program Report.

## 2. Energy context in Morocco

### 2.1. Overview

Morocco is the only country in North Africa with no substantial fossil fuel reserves, unlike its neighbors Algeria and Mauritania, who have large reserves of oil and gas, the kingdom must therefore rely on foreign imports of energy as the economy grows.

In 2010, Morocco imported 97 percent of its energy, making it the largest energy importer in Africa and therefore economically sensitive to energy prices of the global market, despite his large underdeveloped potential for renewable energies[26].

The Moroccan government is predicted to face a significant challenge from an energy security, fiscal, and environmental perspective, because the primary energy demands are predicted to increase to four times over the next 20 years, when the current power production is insufficient to meet the demand, especially with the probability of the energy prices to keep increasing in the near future.

### 2.2. Present energy demand & supply

Morocco's Total Primary Energy Supply (TPES) has grown considerably due to the rapid economic growth of the last years:18.9 million tons of oil-equivalent (Mtoe) in 2014 with a growth of 60% compared to 2004.

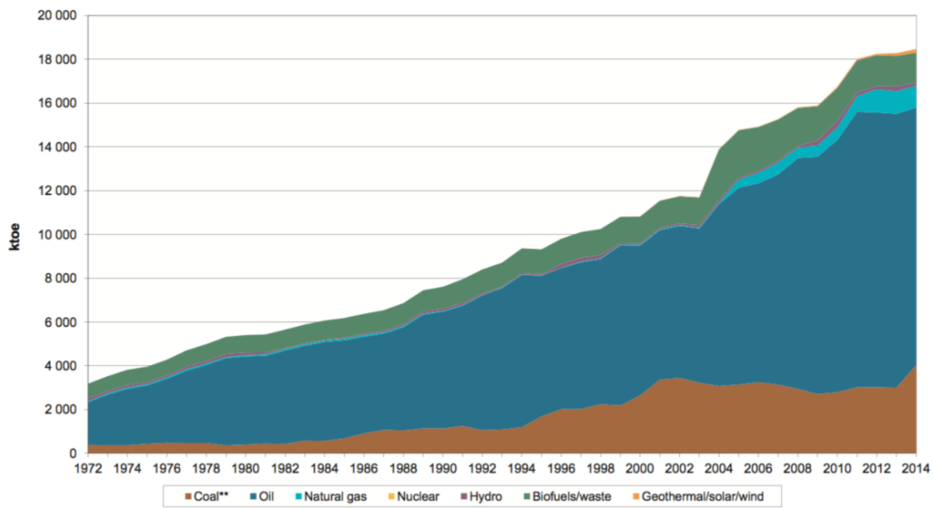


**Figure 8 Total primary energy supply in 2014. (IEA)**

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26MEMEE (Ministry of Energy, Mines, Water and Environment of Morocco.

Morocco's energy mix in 2014 was and is still, as shown in the figure 12, dominated by oil, which represented 63,6% of TPES (a fall from 66.7% the previous year). Coal accounted for a further 21.9%, followed by biofuels and waste (7.4%), natural gas (5.4)and, to a small extent, hydropower (0.8%) and geothermal/solar/wind (0.9%).

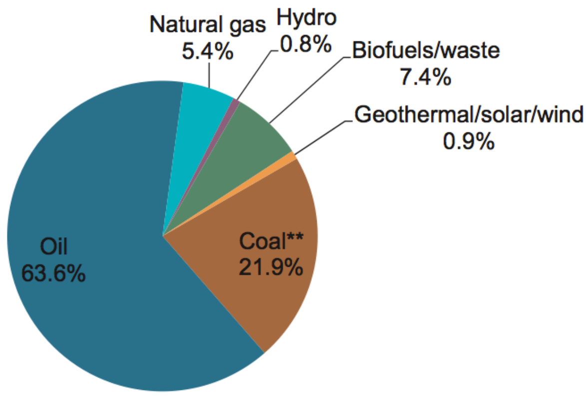


**Figure 9 Share of total primary energy supply in 2014**[27]

To be able to manage the demand growth in a sustainable way, Morocco's renewable energy plans began to take form in 2009, through the law 13-09, which develops the legal framework for general renewable energies development, and opened partially the electricity market to competition for the production of power from renewable sources, allowing to sell power directly to large consumers.

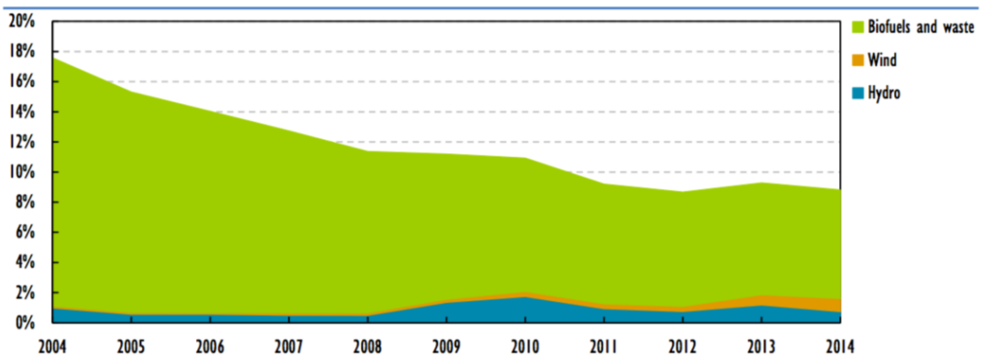


**Figure 10 Percentage of TPES sourced from renewable fuels in 2014.(IEA)**

Renewable energy in Morocco accounted for nearly 1.8 Mtoe in 2013, equivalent to 9.4% of TPES (see figure below), the share of renewables in TPES over the last two decades varying between 8% and 12%, mainly consequence of the volatile annual rainfall. While the supply of biofuels and waste had been increasing historically, since 2004 it has been decreasing, and for the last two years

27International Energy Agency report on Morocco has supplied between 7-7.5% of the TPES. Biofuels – the main source of renewable energy in Morocco – dropped from 16% of TPES in 2004 to 7.2% in 2014, when hydropower ranged from just below 1% of TPES in 2004 to 1.75% in 2010, accounting for 0.74%in 2014. Wind power was initiated in 2000 and had increased thirtyfold by 2014[28].

However, Morocco's renewable energy industry, however, is in the early stages of development, and an additional 10.100 MW of renewable energy capacity must be developed by 2030, with 4.560 MW planned for solar, 4.200 MW for wind, and 1.130 MW for hydro to comply with targets[29].

Morocco's Total Final Consumption (TFC) was 14.3 Mtoe in 2012 and increased drastically since the 1970's.

Morocco's electricity generation grew by 6-7% per year between 2002 and 2012 to satisfy the demand. The country's total installed power generation capacity of 7.994 MW generated 28 TWh of electricity in 2014.

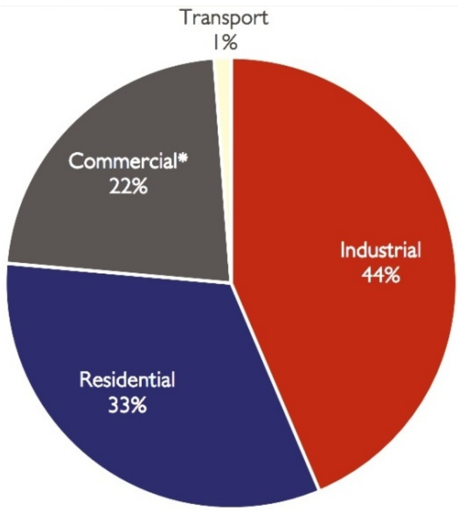


**Figure 11 Electricity consumption by Customer Class[30].**

28International Energy Agency. Clean Energy Technology Assessment Methodology Pilot Study.

29Renewable Energy Growth in Morocco. Middle East Institute. 2016.

30 International Energy Agency Report on Morocco, 2012

Morocco also imports electricity from abroad (principally Spain and Algeria). The industry sector is the biggest consumer of electricity in Morocco (43,6%), followed by the residential sector (32.8%), which also represents a challenge for the next years after the new building energy efficiency regulation, and the commercial sector including agriculture (22.4%), while the transport sector accounts only for 1.2% of the electricity demand.

### 2.3. Projections and challenges

According to MEMEE (Ministry of Energy, Mines, Water and Environment), future primary demand could reach 26 Mtoe in 2020 and 43 Mtoe in 2030 (between 36,6 and 54,5 Mtoe). Estimations for Morocco's future electricity consumption differ but MEMEE estimates the national consumption to increase on average by 6% per year between 2014 and 2025, reaching 49 TWh/y by 2020 and 65 TWh/y by 2025.

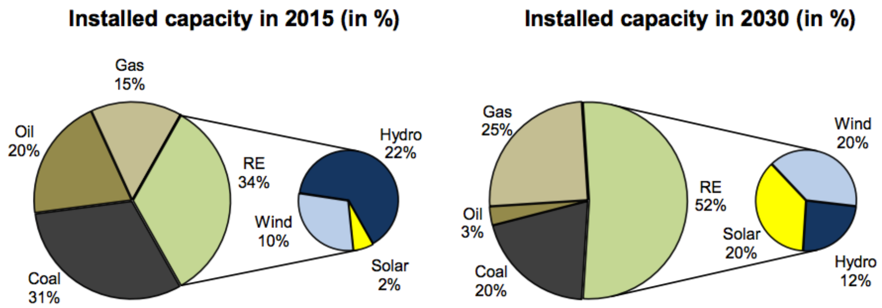


**Figure 12 Shares of installed capacity in Morocco for the years 2015 and 2030. Calculations based on ONEE (National Office of Electricity and Water) and MEMEE data[31].**

However, the government has previously modeled other scenarios, as explained in the figure below, including a high electricity demand scenario, which sees demand increasing at a higher rate 7-7.5% per year to 2030). According to Moroccan government projections, electricity generation from all fuels – except oil products – will increase to meet the official forecast growth in demand, with an estimated difference of almost 25% between a policy range scenario and the actual one. Other studies also project that long-term electricity demand could be significantly higher than the government's modeling.

31Project: Middle East North Africa Sustainable ELECtricity Trajectories (MENA-SELECT). 2016

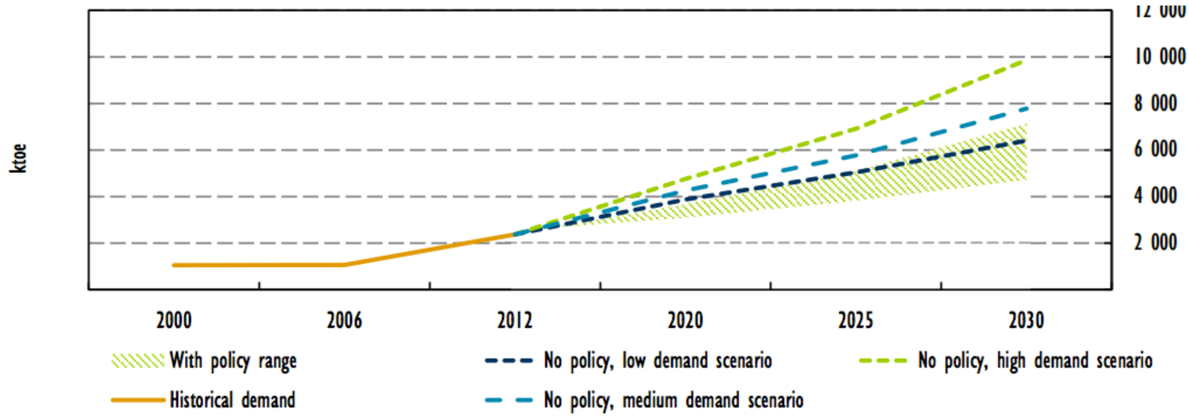


**Figure 13 Projections of electricity demand, Morocco[32].**

Collaboration projects are also being implemented in order to strengthen the connection between the southern and northern shores of the Mediterranean Sea, and Morocco, due to its strategic location and increasingly liberalized electricity market, is actively examining the possibility of exporting electricity to Europe and the Middle East.

Despite the fact that Morocco is a developing country, it has also taken a global leadership position on climate change mitigation, by planning to reduce GHG emissions by 13% unconditionally and by 35% conditionally by 2030, according to its INDC submitted ahead of COP21. In 2016, Morocco hosted the COP22 in Marrakech and committed to supply 42% to its electric demand by 2020, and 52% by 2030 with renewable energy sources.

Nevertheless, the energy and electricity system in Morocco is characterized by strategic challenges : despite Morocco's effort in reframing renewable energy policies, the national energy consumption is still highly dependent on fossil energies, the total $CO_2$ emissions therefore anticipated to follow the rising demands and increase in the mid-long term before a transition.

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32MEMEE. Stratégie Energétique Nationale: Enjeux, Perspectives et Réalisations. National Energy Strategy: Issues, Perspectives and Results. 2015

Notes: The "*No policy, low demand scenario*" represents a scenario in which there are no policy interventions to increase energy efficiency and the economy grows at the historical average rate; the "*No policy, medium demand scenario*" represents a scenario in which there are no policy interventions to increase energy efficiency and the economy grows at a medium rate; the "*No policy, high demand scenario*" represents a scenario in which there are no policy interventions to increase energy efficiency and the economy grows at a high rate; the "*with policy range*" represents the range of electricity demand if the government introduces energy efficiency policies and under and range of different economic growth scenarios.

Additionally, meeting Morocco's growing demand will require substantial investments in additional power generation capacity, transmission and distribution infrastructure as well as storage. Also, the integration of large amounts of intermittent renewable energies capacities with different load types will create challenges for maintaining grid stability, power balancing and reliability of supply.

While subsidies for gasoline, diesel and kerosene were almost eliminated since 2007, electricity prices in Morocco do not represent the real costs as they are below average costs of production and transmission. This creates a significant financial burden on the national budget[33].

Finally, water conservation is another strategic driver affecting technology selection. Technologies that use water in abundance for energy production and cooling (such as hydro and coal-fired power plants) may compete with other water uses. With climate change set to exacerbate water scarcity due to decreased rainfall, energy technologies that can minimize the use of water will be a priority for Morocco[34].

### 2.4. Background and existing programs

Biomass is a traditional resource in Morocco, mostly in the form of wood, which was unfortunately harvested in an unsustainable way. It is still widely used in rural areas but also in the commercial sector (community wood-fired ovens and baths). Although 350 anaerobic digesters were introduced into Morocco in the early 1980s, and some 45% of existing digesters are not in operation (Beraich, Bakasse and Arouch, 2014), private industries are increasingly operating biomass transformation plants for their own energy supply, especially those who can benefit directly from their own residues (i.e the principal sugar producer in Morocco, Cosumar, who installed and operates a sugarcane bagass boiler plant, for savings of about 32.000 Teq C02[35], or the case of the automobile industry Renault in Tangier).

Biomass represents a significant untapped resource because of the strong agricultural background of the country, and the increasing potential of agribusiness, industrial, and urban areas waste that could be exploited.

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33MENA-SELECT . Project: Middle East North Africa Sustainable ELECtricity Trajectories

34IEA. Clean Energy Technology Assessment Methodology Pilot Study. 2016

35Official website of Cosumar

Several programs are currently being run by the Morocco government, principally through the ADEREE, the Agency for Renewable Energy and Energy Efficiency, which is tasked with identifying and evaluating the potential for renewable energy and energy efficiency in Morocco in general, and which has undertaken a national biomass resource assessment which is ongoing, and the German Society for International Cooperation (GIZ) collaborates with Moroccan governmental entities on various projects on renewable energies and energy efficiency.

Also, as part of national strategies, the Ministry of Energy, Mines, Water and Environment (MEMEE) is developing a "National strategy for the valorization of biomass", which, in conjunction with the "Green Plan" (a national strategy oriented to agriculture, with the objective to increase the share of agriculture in the GDP, develop the sector, and improve the technologies of production at all levels), could help improve the efficiency of the different pathways to exploit biomass sources, in addition to provide more bulk source.

## 3. Study

### 3.1. Comparative study of agricultural crops

In order to evaluate the potential of biomass waste generated by agriculture, a first collection of data the statistical report of the Ministry of Agriculture of Morocco has been done in order to determine and rank the major crops on a national scale by their usable agricultural area and production in tons in one year to calculate the yield (see table 4 below, highest yields are indicated in green shades).

| Agricultural Crop | Production Area (1000 ha) | Production (1000 t) | Yield (t/ha) |
|---|---|---|---|
| **Cereals** | **5 457,9** | **11 681,8** | **2,1** |
| Soft wheat | 3 273,8 | 8 074,6 | 2,5 |
| Barley | 2 000,2 | 3 397,0 | 1,7 |
| Corn | 125,1 | 92,3 | 0,7 |
| Oat | 40,5 | 46,3 | 1,1 |
| Rice | 6,7 | 53,6 | 8,0 |
| Sorghum | 5,1 | 5,2 | 1,0 |
| Other cereals | 6,5 | 12,9 | 2,0 |
| **Oleaginous crops** | **51,8** | **87,1** | **1,7** |
| Peanut | 13,9 | 33,7 | 2,4 |
| Sesame | 1,0 | 1,1 | 1,1 |
| Sunflower | 36,9 | 52,4 | 1,4 |
| Sugar crops | **67,1** | **4 044,2** | **60,3** |
| Sugar beet | 58,4 | 3 601,1 | 61,6 |
| Sugar cane | 8,6 | 443,1 | 51,3 |
| **Market gardening** | **258,8** | **7 612,1** | **29,4** |
| Tomato | 17,0 | 1 380,5 | 81,4 |
| Potato | 63,7 | 1 910,7 | 30,0 |
| Onion | 32,0 | 822,6 | 25,7 |
| Other market gardening | 146,2 | 3 498,4 | 23,9 |
| **Citrus** | **117,0** | **1 896,8** | **16,2** |
| **Almond** | **159,7** | **93,3** | **0,6** |
| **Olives** | **1 006,5** | **1 144,3** | **1,1** |
| **Date palm** | **57,9** | **95,0** | **1,6** |
| **Vignes** | **44,6** | **418,4** | **9,4** |
| Wine Grape | 9,3 | 125,1 | 13,5 |
| Table grape | 35,3 | 293,3 | 8,3 |

**Table 6 Yield of the principal crops in Morocco for the period 2014-2015**

The yield is calculated as following : $Y = \frac{P}{Ap}$

**Y**: Yield of crop in t/ha
**P**: Production of crop in t
**Ap**: Area of production in ha

Crop yields are subject to climatic conditions, soil fertility as well as farming practices and harvesting methods chosen, this value varies every year and from a region to another.

Cereals represent, in terms of area, approximately 80% of the total usable agricultural area in Morocco, and the production reached 11,7 million of tons in 2014/2015.

Forage crop culture is need-oriented, it is consisting mainly of alfalfa, and it should not be included as part of the assessment because it is common practice to use it to feed livestock, the residues are non-existent.

We assume that, based on literature data and speeches experts, crop residues which are very low, which do not technically or economically permit their collection, residues that are indispensable for the conservation of organic soils (protection against erosion or maintenance of soil fertility), are not considered in this study and therefore do not figure in Table 4.

The criteria that led the choice of the crops are the crop acreage, the biomass quality, which is the set of properties for different bioconversion routes and the suitability of the residues for energetic use, based on expert opinion and the Part I of the study, but also the Residue yield, that indicates the amount of recoverable residue from a crop during the harvest process, and that we calculated as :

$$Residue\ Yield = RPR * Y$$

where:

**Residue Yield**: The residue yield gives the quantity of residue generated from one hectare in a specific region. (t/ha)

**Yield**: Yield of crop (t/ha)

**RPR** : Residue per Product Ratio (t/ha), is the amount of residues produced, and thus potentially available for bioenergy production. It is not a average value, dependent of the yield on one side but also on stresses the crop experiences during growth. This method enables the calculation of the amount of residues in multicropping systems. In this study, a list of mean RPR values of our crops was determined as a synthesis of literature review (some references include Auke Koopmans and Jaap Koppejan 1998, Perlack, Turhollow 2003, Kim, Dale 2004, Hiloidhari, Baruah 2011a, Nelson et al. 2004, Nelson et al. 2004, Jingura, Matengaifa 2008).

| Agricultural Crop | Production area (ha) | Yield (t/ha) | RPR | Residue Yield (t/ha) |
|---|---|---|---|---|
| **Cereals** | 5 457,9 | | | |
| Rice | 6700 | 8 | 1 | 8 |
| Wheat | 3273800 | 2,5 | 1,3 | 3,3 |
| Oat | 40500 | 1,1 | 1,4 | 1,6 |
| Barley | 2000200 | 1,7 | 1,5 | 2,6 |
| Maize | 125100 | 0,7 | 1,1 | 0,8 |
| Sorghum | 5100 | 1 | 1,3 | 1,3 |
| Oils Crop | 51800 | 1,7 | 2,3 | 4 |
| **Sugar Crop** | | | | |
| Sugar Cane | 8600 | 51,3 | 0,3 | 15,4 |
| Sugar beet | 58400 | 61,6 | 0,4 | 24,6 |
| **Vegetable Crops** | | | | |
| Tomato | 17000 | 81,4 | 1,3 | 101,8 |
| Potato | 63700 | 30 | 0,6 | 18 |
| **Citrus** | 117000 | 16,2 | 2 | 32,4 |
| **Olives** | 1006500 | 1,1 | 1,4 | 1,5 |
| **Vines** | 44600 | 13,5 | 1,2 | 16,2 |
| **Almonds** | 159700 | 0,6 | 2 | 1,2 |

**Table 7 Residue yield of the selected crops**

### 3.2. Quantitative estimation of livestock waste :

Within the agricultural sector, the livestock industry is one of the most important components of Morocco's agricultural economy, with a share of approximately 30%. The total population of livestock (including cattle, sheep and goat) was of 28 million and 320 million poultry in the 2014/2015 period, according to the national statistics.

In the Moroccan context, sheep, goat and male cattle livestock grazing, destined for meat, is traditionally done out of the farming housing, which makes the produced manure dispersed and hard to quantify/collect. Additionally, the differences in farming methods, and dispersed and diffused data on different levels, and the fact that the best yield is obtained from dairy cattle manure, will make us focus on dairy cattle manure potential only in this study.

| Livestock (2014/2015) | Sheep | Cattle | Goat |
|---|---|---|---|
| Population (x1000) | 18509 | 3291 | 6231,4 |
| | | TOTAL | 28031,4 |

**Table 8 Livestock population in Morocco**

The population of dairy cattle is estimated to 2,4 millions, which we will take as a basis for the estimation of the potential of biomass from livestock.

According to World data bank, an average of 45-50 Kg of manure is produced daily by head, with approximately 13-15% of solid portion.

| Dairy cattle population(head) | Manure (Kg/day/head) | Total (t/year) |
|---|---|---|
| 28031400 | 45 | 40.096.710 |

**Table 9 Total manure production potential for dairy cattle in 365 days.**

## 4. Results

The study is based on the estimation of the theoretical potential, according to Smeets et al. (Smeets et al. 2007, Smeets et al. 2006) definition, it includes the bioenergy production from residues, limited by fundamental physical and biological constraints and the current production of agricultural crops.

### 4.1. Theoretical potential from agricultural residues

The following equation is used to calculate the theoretical potential of the harvest, for each residue type a different RPR is used , as explained above:

$$THP = Y * RPR * Ap * (1 - MC) * LHV$$

where :

**THP :** Theoretical potential of the agricultural residues in MJ
**Yield** : Yield of crop (t/ha)
**RPR :** Residue per Product Ratio (t/ha)
**Ap** : Area of production in ha
**MC :** Moisture content as a percentage of the fresh matter
**LHV :** Lower heating value of the residues in MJ/t

| Agricultural Crop | Pa (ha) | Y(t/ha) | RPR | MC | LHV (MJ/t) | THP (MJ) |
|---|---|---|---|---|---|---|
| **Cereals** | 5.457,9 | | | | | |
| **Rice** | 6.700 | 8 | 1 | 0,05 | 13.000 | 661.960.000 |
| **Wheat** | 3.273.800 | 2,5 | 1,3 | 0,16 | 17.200 | 153.724.552.800 |
| **Oat** | 40.500 | 1,1 | 1,4 | 0,14 | 15.100 | 809.936.820 |
| **Barley** | 2.000.200 | 1,7 | 1,5 | 0,15 | 17.000 | 73.702.369.500 |
| **Maize** | 125.100 | 0,7 | 1,1 | 0,2 | 17.700 | 1.363.990.320 |
| **Sorghum** | 5.100 | 1 | 1,3 | 0,14 | 17.000 | 96.930.600 |
| **Oils Crop** | 51.800 | 1,7 | 2,3 | 0,09 | 18.000 | 3.317.572.440 |
| **Sugar Crop** | | | | | | |
| **Sugar Cane** | 8.600 | 51,3 | 0,3 | 0,3 | 18.000 | 1.667.660.400 |
| **Sugar beet** | 58.400 | 61,6 | 0,4 | 0,3 | 17.600 | 17.728.184.320 |
| **Vegetable Crops** | | | | | | |
| **Tomato** | 17.000 | 81,4 | 1,3 | 0,24 | 13.000 | 17.773.527.200 |
| **Potato** | 63.700 | 30 | 0,6 | 0,17 | 6.400 | 6.090.739.200 |
| **Citrus** | 117.000 | 16,2 | 2 | 0,2 | 13.800 | 41.850.432.000 |
| **Olives** | 1.006.500 | 1,1 | 1,4 | 0,07 | 19.500 | 28.109.431.350 |
| **Vines** | 44.600 | 13,5 | 1,2 | 0,09 | 17.700 | 11.637.629.640 |
| **Almonds** | 159.700 | 0,6 | 2 | 0,15 | 17.000 | 2.769.198.000 |
| | | | | | **TOTAL (MJ)** | **361.304.114.590** |
| | | | | | **TOTAL (Mtoe)** | **8,6** |
| | | | | | **TOTAL (MWh)** | **100.018.000** |

**Table 10 Theoretical potential of agricultural residues (toe)**

The values of moisture content and LHV were collected from literature studies, in some cases where the residues had a range of values (olive residues for example, with MC and LHV varying between olive pits and pommace, the mean value was taken).

### 4.2. Theoretical potential from livestock manure

Overlapping the quantities obtained with literature on biogas potential from manure, and according to the existing references to determine the yield (Böhni Energie & Umwelt, Solomie A. Gebrezgabher et al., T. Amon et al.), considering 10% of dry matter[36], we obtain the following :

| Input | (t) | Biogas Yield (m3/t) | Total biogas Potential (m3) |
|---|---|---|---|
| Wet Dairy Manure | 40.096.710 | 20 | 801.934.200 |
| | | Total (Mtoe) | 0,7 |
| | | MWh | 8,45 |

**Table 11 Theoretical potential of livestock waste**

With a livestock waste of 40 million tons of dairy cattle manure, we would be able to reach a theoretical potential of 0,7 Mtoe of energy.

Gas yields depend highly on dry matter content, storage feedstock, handling feedstock, and the length of time in the digester, but also the type of AD plant and the conditions.

For an exact calculation, feedstock testing is definitely necessary.

The total theoretical potential of energy is therefore estimated as :

| | Potential (Mtoe) |
|---|---|
| Livestock waste | 0,7 |
| Agricultural residues | 8,6 |
| Total | 9,3 |

**Table 12 Theoretical potential from agriculture residues and livestock waste**

[36] IEA, Biogas from Energy Crop Digestion

## 5. Discussion and Conclusions

- The total potential obtained represents about half of the Total Primary Energy Supply of Morocco in 2014 (18,9 Mtoe) , and 36% of the demand projected for 2020.

- The total theoretical potential from agriculture residues and livestock on a national scale is of approximately 9,3 Mtoe, 7,5% of it from the livestock manure, knowing that, as mentioned, only dairy cattle is included in this study, due to the dispersed nature of sheep, goat and male cattle grazing and farming.

- The biggest share of energy potential resides in the cereal agriculture, which theoretically provides 38,9% of the total potential. Discussion with experts highlighted that in practice, a small portion of this potential actually remains for exploitation, due to the generalised common use of cereal residues as livestock forrage, but also an occasional fungal infection that occurs in the cereal mills. A sustainable management of the cereal harvested area also requires a recovery of the residues, approximately at a range of 50%.

- An important share of the biomass potential are the market gardening/vegetable crops (tomato plant crops for instance), which are particularly promising for energy recovery. These plants are usually harvested in glasshouses, and grow hanging on a cable till reaching 2 or 3 meters of height, before being cut. This culture, because it takes place mainly in plastic tunnels, requires a clearing of the glasshouse after the end of the culture to leave room for the next plant, usually at a short rotation period. The huge quantity of plant residues represents an interesting potential.

- The production of biogas from manure is particulary sustainable (when critera are respected) as an energy source because there is no need for additional land use for its production. Reusing the product of manure transformation, by applying digestate to land is an attractive option in terms of environmental issues, because it allows nutrients to be recovered and reduces loss of organic matter suffered by soils under agricultural exploitation.

- The nature and properties of agriculture residues in Morocco can be roughly divided to "dry biomass", such as cereal residues, seeds and pits, that would be transformed efficiently through gasification or combustion, and the "wet residues", gathering all the fruit and vegetable crop residues, characterized by a higher moisture and cellulose content, thus making them suitable for digestion and biochemical processes.

- For the further development of biomass as a source of energy, the data must be verified more exactly at a local level, and compared to empirical data on field, in order to allow a successful implementation due to the high "case-basis" of energy production from agricultural residue.

  This is why it is important to take into consideration the "Plan Vert", the national strategy on going by the Ministry of Agriculture, which, as explained previously, is planning in general to increase the share of agriculture in the GDB, but also to restructurate and organize the field at all stakeholder levels, and aims to improve the technologies and good practices. This will have a positive effect on the feasibility and yielding of biomass production, collection and transformation.

In the context of a country like Morocco, which is highly dependent of energy importations, the increased deployment of modern biomass based systems, and renewable energies in general, is a fundamental pathway to take in order to reach energy security in general, and improve the rural conditions in particular . In any case, production and use of biomass should be sustainable in terms of the social, environmental and economic perspectives.

Success of biomass based projects depends on the understanding of the stakeholders on all levels which have to understand biomass resource base, its purposes and potential use.

All these aspects point strongly to the importance of coordination and coherence of policies directing the supply and use of biomass for different purposes, the success of biomass based projects depending tightly on the coordination of the stakeholders on all levels, politically, economically and environmentally.

Thus, governmental regulations are indispensable to provide and secure a stable economic and ecologic framework conditions for a sustainable and win-win scenario.

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